ETH zürich

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Towards Reliable Systems: A Scalable Approach to AXI4 Transaction Monitoring

Chaoqun Liang, Thomas Benz, Alessandro Ottaviano,

Angelo Garofalo, Luca Benini, Davide Rossi

pulp-platform.org

@pulp_platform

company/pulp-platform

youtube.com/pulp_platform

PULP Platform

Open Source Hardware, the way it should be!

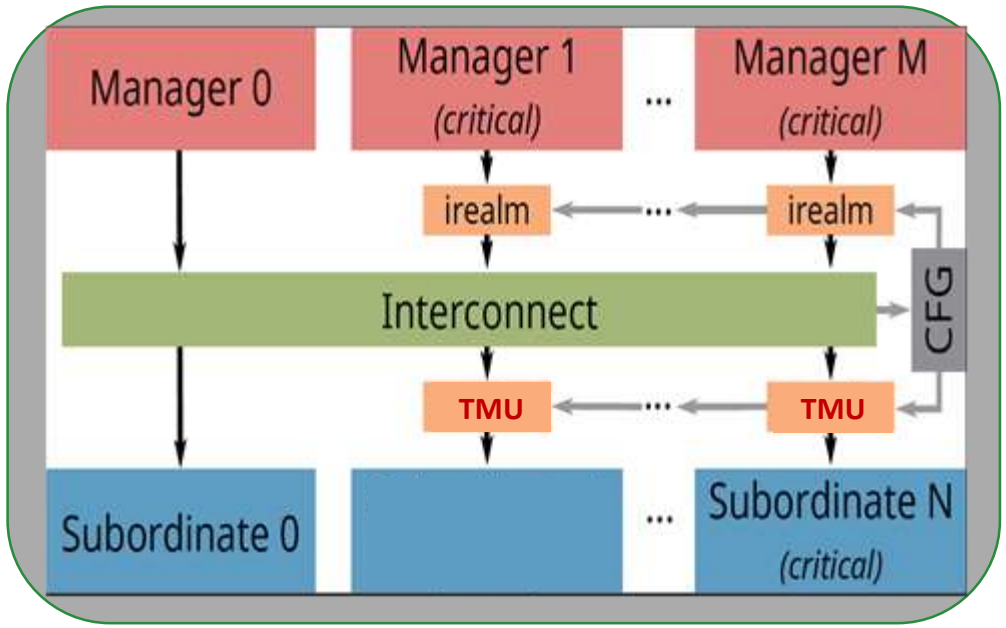
Introduction

- Safety-critical applications require high reliability in SoC designs
- Reliability of the system bus is crucial
- AXI4 protocol widely adopted standard
  - high throughput and low latency
  - support for multiple transaction IDs and multiple outstanding transactions.
- Failures can originate from both managers and subordinates
- **Transaction failures may cause deadlocks, data corruption, and complete system outages**
- Transaction monitoring and fault management
- **Gaps in SOTA solutions:**
  - Lack comprehensive monitoring with granularity and scalability
  - Lack monitoring support for multiple transaction IDs and multiple outstanding transactions

Our Work

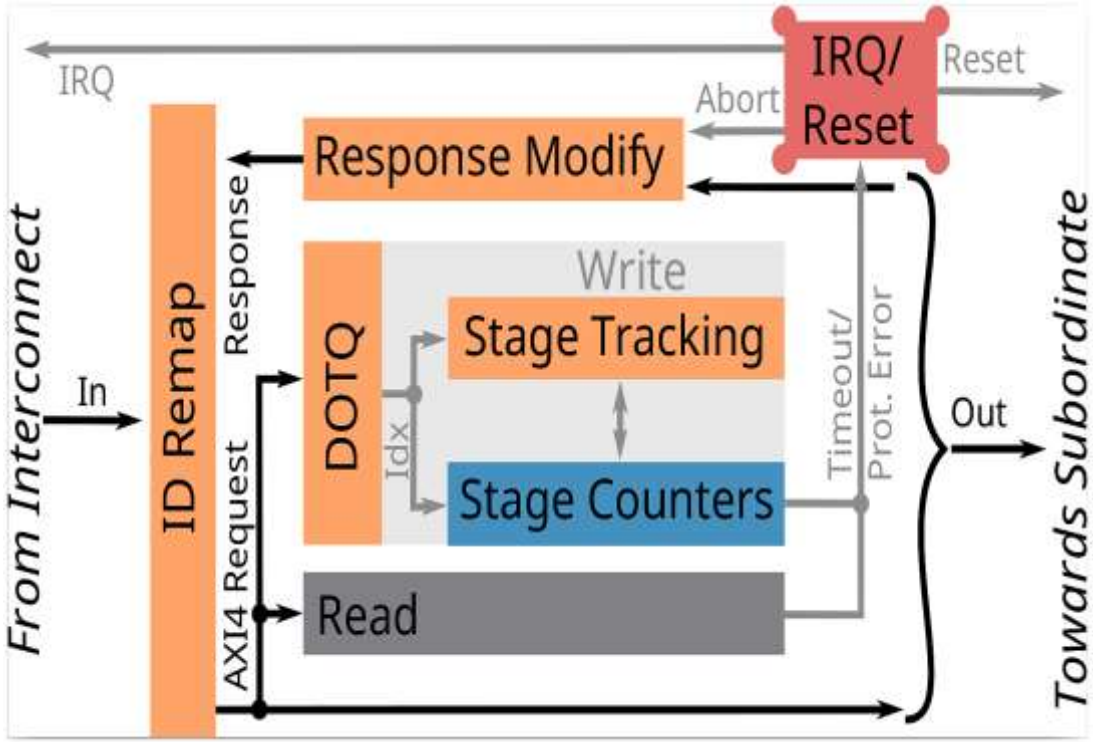
Transaction Monitoring Unit (TMU)

- A drop-in IP designed for AXI subordinate endpoints.
- Continuously monitors multiple outstanding transactions between AXI4 interconnect and subordinate devices.
- It detects protocol violations(handshake, ID mismatch, unrequested responses..) and timeouts.
- It triggers recovery actions by isolating faults and requesting a reset towards the faulty subordinate to minimize system disruption.



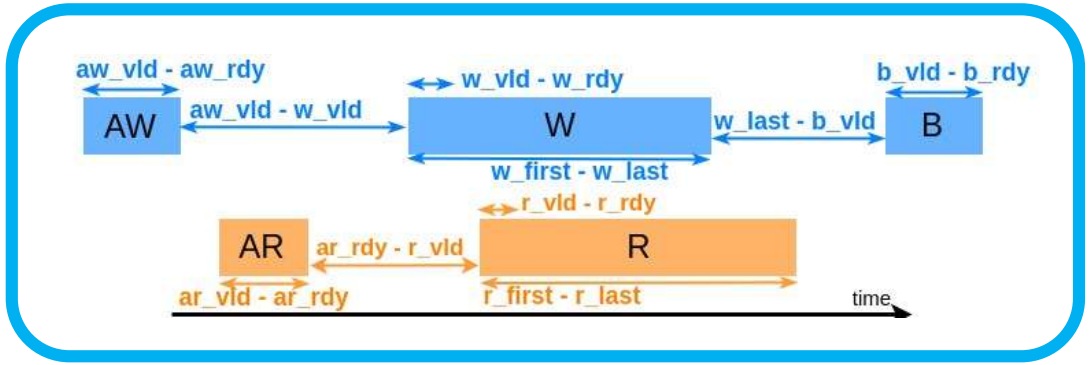
TMU Architecture

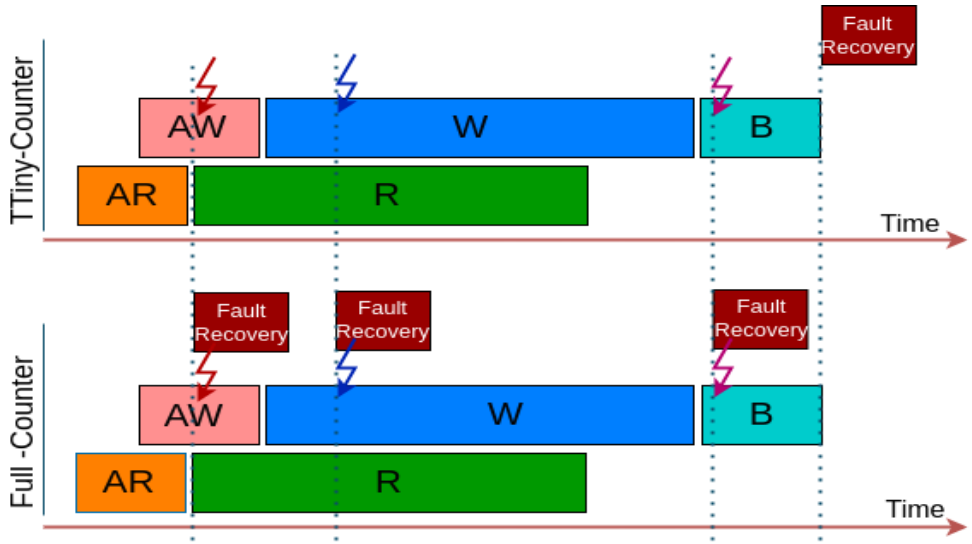
- **ID Remapper** optimizes ID utilization
- **Write and Read Guards,** each with:
  - **DOTQ** manages multiple transaction IDs and outstanding transactions
  - **Stage Tracking** monitors transaction progress and validates protocol rules
  - **Stage Counters** measures latency and detects timeouts
  - **Configurable prescaler** scales monitor timing to trade off between tracking precision and hardware cost
- **Response modifier** adjusts and overwrites responses before sending them back to the manager.

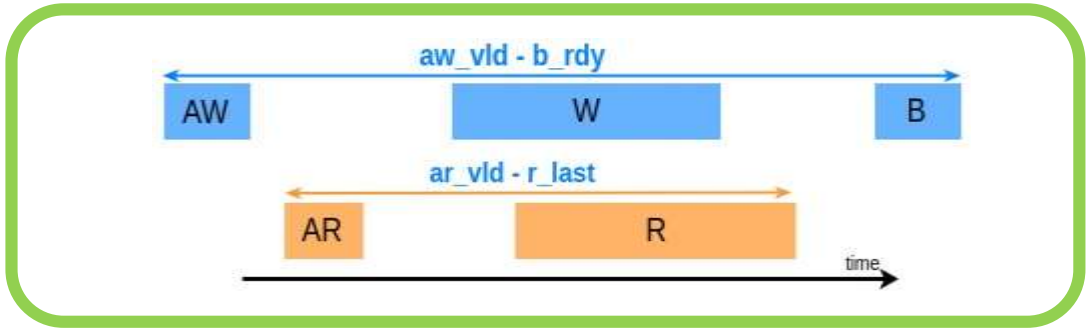


TMU Variants – Full-Counter vs. Tiny-counter

Full-Counter (FC)	Tiny-Counter (TC)
Fine-grained tracking across stages within transactions	Uses a single counter per transaction
Early fault detection and precise latency analysis	Minimal area overhead

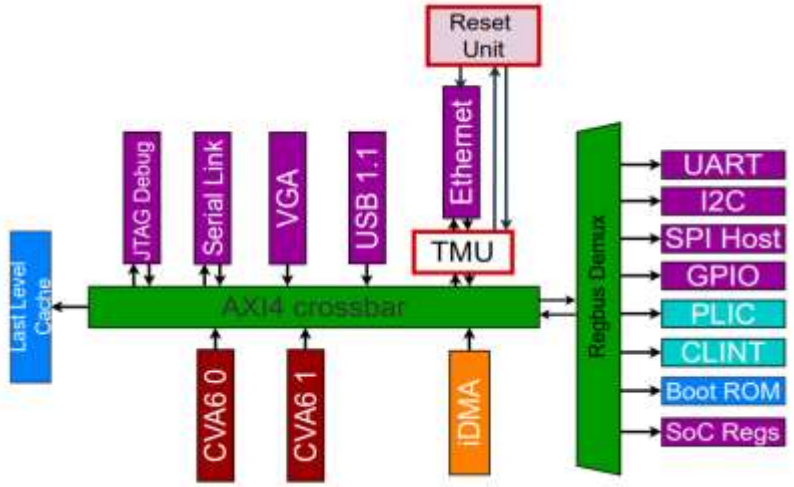






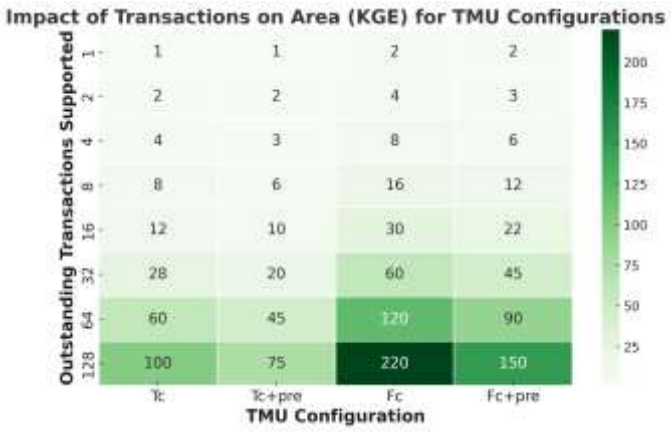
Evaluation and Results

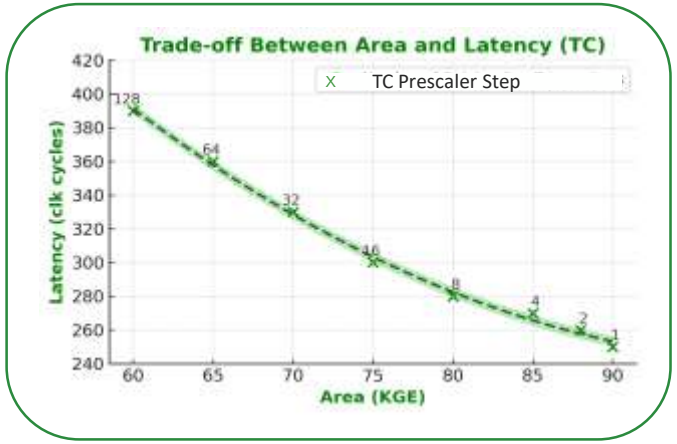
- We integrated into Cheshire platform (RISC-V CVA6-based SoC) monitoring RGMII Ethernet peripheral.

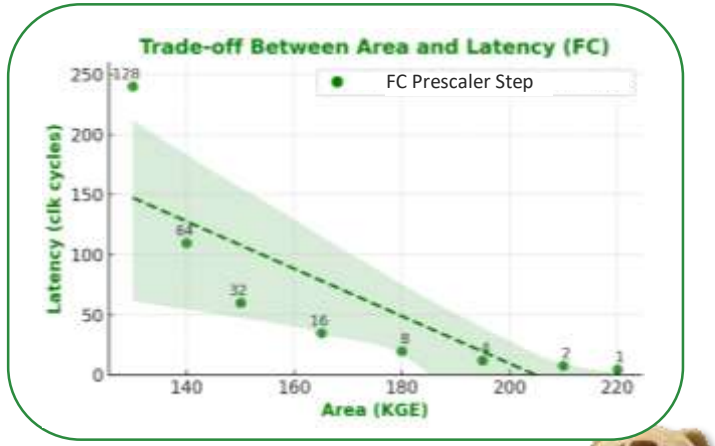


Cheshire by Pulp-platform

- We synthesized TMU in GF12 technology under four configurations: FC and TC, with and without prescaler.







Conclusion

- Real-time detection of protocol violations and timeouts, along with fault recovery.
- Two distinct implementations:
  - Tiny-Counter for minimal area and transaction-level monitoring
  - Full-Counter for detailed, stage-level monitoring.
- Supports multiple outstanding transactions monitoring with dynamic time budgets
- Logs performance metrics for in-depth analysis
- Drop-in, scalable solution that boosts reliability and observability in AXI4-based SoCs

PULP Platform
Open Source Hardware, the way it should be!

Thank you!

pulp-platform.org
@pulp_platform
company/pulp-platform
youtube.com/pulp_platform

Institut für Integrierte Systeme, ETH Zürich
Gloriastrasse 35
Zürich, Switzerland

DEI, Università di Bologna
Viale del Risorgimento 2
Bologna, Italy

ETH zürich
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA